Tilting of Posterior Mandibular and Maxillary Implants for Improved Prosthesis Support
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Rehabilitation of atrophied edentulous arches with endosseous implants in the posterior regions is often associated with anatomic problems such as jaw shape and location of the mental loop, mandibular canal, and maxillary sinuses. The purpose of this investigation was to modify the method for implant placement in the posterior part of the jaws to extend fixed implant-connected prostheses further distally, and to reduce the length of cantilevers in complete-arch prostheses without transpositioning the mandibular nerve or performing bone grafting in the maxilla. Forty-seven consecutive patients were treated with implants (25 patients/36 mandibular implants, 22 patients/30 maxillary implants) placed in tilted positions. They were followed a mean of 40 months (mandibles) and 53 months (maxillae). In the mandible, implants close to the mental foramina were tilted posteriorly approximately 25 to 35 degrees. In the maxilla, the posterior implants were placed close to and parallel with the sinus walls and were tilted anteriorly/posteriorly approximately 30 to 35 degrees. Patients gained a mean distance of 6.5 mm of prosthesis support in the mandible and 9.3 mm in the maxilla, as a result of implant tilting. There were no implant failures in mandibles. The cumulative success rates in the maxilla at 5 years were 98% for tilted implants and 93% for non-tilted implants. Paresthesias of the mental nerve were observed on 4 sides during the first 2 to 3 weeks after implant placement. Analysis of the load distribution in one mandibular case showed no significant difference between tilted and the non-tilted implants, and the improved prosthesis support was confirmed. Satisfactory medium-term results concerning osseointegration and significant extension of prosthesis support show that the method can be recommended. This technique may allow for longer implants to be placed with improved bone anchorage. (INT J ORAL MAXILLOFAC IMPLANTS 2000;15:405–414)

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Edentulous patients treated with prostheses supported by osseointegrated implants can realize improved masticatory function in terms of chewing efficiency and bite force.1 However, rehabilitation of edentulous posterior regions with endosseous implants is often associated with problems of anatomic origin, and bite forces are at their greatest further back in the dentition.2 According to the original concept for the placement of Brånemark System implants in an atrophied completely edentulous arch, the implants are placed in a fairly upright position.3,4 Consequently, it is often necessary to fabricate a bilateral cantilever that is up to 20 mm in length so as to provide the patient with good chewing capacity in molar regions.

MANDIBULAR ANATOMY

An oval-shaped mandibular body, where the mental foramina are located on each side of the horizontal curvature of the arch, differs from the rectangular type of mandible, where the foramina are located on
a frontal straight line in the incisive area (Figs 1a and 1b). Placement of implants between the mental foramina in oval-shaped mandibles, especially when the mental foramina are positioned posteriorly, permits favorable implant positions, without the need for long posterior extensions, and masticatory forces will be evenly distributed between the implants. However, in patients with rectangular mandibles, the implants are forced into a more or less straight-line configuration. In these situations the load force on the cantilevers in the molar regions will lead to bending moments on the implants, introducing high stress in both bone and implant components. This situation may be more critical in patients with natural teeth or stable prothetic restorations in the maxilla.

Another limitation for posterior placement of mandibular implants is the mental nerve loop, which leads into the mandibular canal. This loop is usually situated 2 to 9 mm anterior to the mental foramina. Thus, an upright distal implant may need to be placed anterior to the mental foramina and the loop to avoid damage to the nerve. Transpositioning of the mandibular nerve is one possibility for placing long and stable implants in the molar regions. However, problems with paresthesias of the mental nerve have been reported.

Another technique is to place short implants above the mandibular canal. However, such implants are anchored only in the superior cortex, which compromises the load-bearing capacity. Short implants are reported to fail more frequently than longer ones. Placement of implants lingual to the nerve canal, through both the superior and inferior lingual cortex, has also been described.

**MAXILLARY ANATOMY**

An important aspect in the rehabilitation of maxillary edentulous patients with endosseous implants is the fact that in many cases there is sufficient alveolar crest volume in the anterior region, while in the premolar and molar regions, severe bone resorption is present. Consequently, it is not possible to place long implants that are equally distributed along the alveolar crest. When gathering the implants in the anterior region of such an arch, there is often a need for a bilateral cantilever length of up to 20 mm or more, so as to give the patient good chewing capacity in the premolar and molar areas.

In the literature there are many recommendations for cantilever length. Cantilever length has been related to marginal bone loss around implants and mechanical failure of the components. Prostheses with cantilevers of 15 mm or less survived significantly better than fixed prostheses with a cantilever length exceeding 15 mm. Calculation of implant load distribution in the maxilla clearly demonstrates the advantage of well-distributed implants in controlling implant loading. Simultaneous bone grafting from the iliac crest or the mandible has been reported, as well as postoperative problems with graft and host side morbidity.

**IMPLANT TILTING**

From the literature it is thus well understood that a spread of implants along the alveolar crest is beneficial for load distribution. The support advantage gained by moving the implant head in the posterior direction is well known, and in this study, tilting of implants...
was used to gain such increased support. Posterior tilting of the distal implant on each side in the mandible and maxilla may reduce cantilever length and as a consequence give rise to better load distribution. In addition to broadening the prosthetic base, the tilting may also allow for improved cortical anchorage and primary stability as well as the use of a longer implant.

Laboratory tests on models\(^2\) and theoretical calculations\(^3\) have indicated that tilted (angled) implants may increase the stress to bone. These studies were performed on single implants. During loading, a tilted single implant may be subjected to bending, leading to increased marginal bone stress.\(^4\) If such an implant is part of a multiple-implant–supported prosthetic restoration, however, the spread of the implants and rigidity of the prosthesis will reduce bending of the implants.\(^5\) In this study the tilting was mostly in the direction of the prosthesis extension, and therefore the possible stress increase related to tilting is anticipated to be negligible.

In the literature, tilting of implants for engaging the pterygoid plate in the posterior maxillae is reported, indicating that this is a predictable procedure for establishing end support for a maxillary prosthetic restoration.\(^6\)\(^-\)\(^9\) In 15 patients followed for a minimum of 3 years, one posterior implant at each end of each complete-arch prosthesis was angled to follow the sinus walls and to penetrate into the cortical bone of the nasal cavity.\(^10\)

This study was carried out to evaluate the clinical success and surgical and prosthodontic effects of posterior extension of the prosthetic base by tilting the most posterior positioned implant on each side of the restorations for both maxillae and mandibles. A biomechanical analysis was also performed on in vivo measurements for implant load distribution.

**MATERIAL AND METHODS**

Twenty-five consecutive mandibular patients (10 male and 15 female, mean age 63.1 years, range 35 to 80) and 22 consecutive maxillary patients (10 male and 12 female, mean age 61.2 years, range 42 to 72) were followed for 40 months (range 35 to 54 months) and 53 months (range 35 to 60 months), respectively. In these patients, 36 tilted mandibular implants and 40 tilted maxillary implants were placed in an angulation position to expand the prosthesis base without grafting or transposition of the alveolar nerve.

All patients were operated under local anesthesia using epinephrine with adrenaline (xylocaine, adrenaline 2%, 3.6 mL) injected on each side of the arch. Postoperatively, the patients were given phe-noxyymethylpenicillin 1.5 g twice daily for 5 days. The patients rinsed their mouths with chlorhexidine (Corsodyl, SmithKline Beecham Consumer Healthcare, Philadelphia, PA) twice daily for 1 week.

**Surgical Technique**

In completely edentulous mandibular situations, incisions were made on top of the alveolar crest, from the first molar on one side to the first molar on the contralateral side with bilateral releasing incisions. Subperiosteal dissection on the lingual and vestibular surfaces was carried out. In partially edentulous situations, similar local flaps were made. The mental foramina were located, and the length and tilting of the mental loop were noted. The most posterior implant was placed close to the anterior wall of the mental loop and parallel with it. Thus, this implant was tilted distally approximately 25 to 35 degrees (Fig 2). This technique provides the following 3 advantages: (1) implant support is moved
posteriorly, (2) implant length is increased, and (3) the implant follows a dense bony structure, the anterior wall of the mental loop, enhancing primary stability. After placement of the posterior implants bilaterally, additional implants were placed in the anterior space between. Flap adaptation and suturing were performed in the usual manner.

For completely edentulous maxillary patients, incisions were made on the alveolar crest from the first molar on one side to the first molar on the contralateral side with bilateral releasing incisions. Subperiosteal dissection on the palatal and vestibular surfaces was carried out. Angulation of the anterior sinus wall was visualized via a hole drilled in the lateral sinus wall. The most posterior implant was placed close to and parallel with the anterior sinus wall. Thus, this implant was tilted distally approximately 30 to 35 degrees. This technique provides the following 3 advantages: (1) implant support is moved posteriorly, (2) implant length is increased, and (3) the implant follows a dense bony structure, the anterior sinus wall, thereby enhancing primary stability. Where a patient had sufficient bone in the tuberosity, a similar procedure was performed for the placement of an anteriorly tilted implant close to the posterior sinus wall (Fig 3). Then the placement of implants in the anterior part of the maxilla was performed. Flap adaptation and suturing were performed in the usual manner.

Abutment placement was performed 3 months after implant placement in the mandible and after 6 months in the maxilla. Healing abutments were used after second-stage surgery in both arches. Later, the prosthodontist changed these to standard or angulated abutments. When implants diverged more than 30 degrees, angulated abutments were used. Otherwise, standard abutments or Esthetic-Cone abutments (Nobel Biocare, Yorba Linda, CA) were applied. At this stage, implant stability was checked by the surgeon; it was checked again later by the prosthodontist. Panoramic radiographic examination was conducted immediately after abutment connection.

**Prosthodontic Treatment**

Prosthodontic treatment began from 1 day to 3 weeks after the abutment connection. Partial prostheses were fabricated of precious metal and porcelain, while complete-arch prostheses were fabricated either with a gold framework or with a titanium framework combined with acrylic resin teeth (Fig 4).

The gained distance of prosthesis support, as a consequence of the tilted implants, was measured on an orthopantomogram as the mesiodistal distance from the point at which the tilted implant supported the prosthesis to the point where an upright implant would have provided support (Fig 5).

**Follow-up**

At the follow-up visits, the prostheses were removed, and implant stability was determined by the prosthodontist. Radiographs were taken to ascertain integration and marginal bone level. The implant was judged successful if it was stable and did not show more than 2 mm of marginal bone loss subsequent to prosthesis connection at any given time. If the implant was deemed stable and functional but bone loss was greater, the implant was classified as surviving. In the calculation of success rates, surviving implants were excluded.
Implant Load Assessment

Strain gauge measurements of implant loading were performed on a patient (Figs 4a and 4b) who had used a distally cantilevered prosthesis supported by 3 implants (1 tilted and 2 non-tilted) in the left half of the mandible for approximately 4 years. The strain gauge technique, described by Glantz et al., relates the strains from 3 strain gauges mounted on the lateral surface of the abutment to axial force and bending moments acting on the implant abutment (axial force is defined as the force acting along the long axis of the abutment/implant). The measuring procedure, including calibration of the individual strain-gauged abutments, was monitored by a specially designed LabView program (National Instruments, Austin, TX).

At the time of registration, all of the patient's original abutments were removed and replaced with strain-gauged measuring abutments. The patient was asked to apply maximum bite force on a specially designed bite fork, which also was equipped with strain gauges, thus enabling measurements of bite force. Repetition of this procedure while the bite fork was moved over the prosthesis gave rise to a series of registrations of forces and moments on the supporting implants, as well as the force applied through the bite fork.

The patient's implant/prosthesis reconstruction was theoretically simulated by a model (Fig 6) based
on a straight bar supported by 3 rigid hinges. This model, like the Skalak model, will predict only axial forces at the supports but not bending moments. Calculations with more refined models, including bending moments and implant flexibility, have shown that this simpler approach is often sufficient for estimations of force distribution. With this simple model, theoretical calculations were performed to estimate the effect on force distribution from the change of support positions caused by tilting of the implants. Because of the simplicity of the model, the results of these calculations should be interpreted as relative differences only.

RESULTS

The cumulative implant success rates are shown in Tables 1 and 2. The success rate was 100% for the mandibular implants, regardless of whether they were tilted or non-tilted. After loading in the maxilla, 1 tilted implant (n = 40) was lost between 3 and 4 years; for the non-tilted implants (n = 98), 2 were lost between 1 and 2 years, 3 were lost between 3 and 4 years, and 1 was lost between 4 and 5 years. This provided a 4-year cumulative success rate of 95.7% for the tilted implants and 92.5% for the non-tilted implants. In the tilted group, 2 implants were classified as surviving after 5 years, based on the bone loss criteria; for the non-tilted implants, this number was 5.

Complications

Postoperatively, suture dehiscence was observed in 4 of 25 mandibular cases and in 3 of 22 maxillary patients. In these cases the cover screws were visible. These patients were instructed to carry out careful oral hygiene and to brush the exposed metal. Paresthesias of the mental nerve were observed on 4 sides during the first 2 to 3 weeks after implant placement. No cases of nerve disturbance were noted at the time of abutment connection.

From a prosthetic point of view, tilted implants result in somewhat less accessibility for the restorative dentist. Otherwise, there were no specific prosthodontic problems found in this study. With respect to maintenance, patients initially seemed to have problems with cleaning distally in their mouths, regardless of whether the implant was tilted or not.

Prosthesis Base Extension

Calculation of the gained distance of prosthesis support, as a consequence of the tilted implants, showed a slight variation between the left and right side in the mandible. The mean length on the left

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side was 6.6 mm (range 3 to 12 mm) and on the right side it was 6.5 mm (range 5 to 10 mm). The mean distance gained in the maxilla was 9.3 mm (range 5 to 15 mm).

**Load Measurement**

Strain gauge measurements on the one patient subjected to in vivo registration (Figs 4a and 4b), showed no significant differences in forces or bending moments on the tilted implant, in contrast to the non-tilted implants supporting the prosthesis.32

Figure 7a shows the influence of the bite fork on the load on each implant. The graph depicts the relative amount of applied axial force counteracted by each implant when bite force was applied at different positions along the prosthesis. As seen in Fig 7a, the maximum amplification for all the implants was approximately 130%. The corresponding 30% amplification is the result of the leverage effects within the structure and is considered to be a small number.5 The bending moments measured during the experiment were all relatively small, rarely above 20 N-cm, corresponding to a lever arm of about 3 mm for the acting force.

To test the accuracy of force registration, the sum of reaction forces was compared to the applied bite force on a percent level. The sum did not always add up to 100%. However, since the sum is derived from the difference of rather large numbers, a tolerance in the measured parameters of 10% is probably sufficient to explain the discrepancy in the diagram. Considering that the implants were not placed vertically, this deviation was thought to be acceptable and the accuracy of the measuring technique was considered confirmed.

The theoretical model, with the implants positioned as in the clinical situation, showed the same general features as the actual measurements (Figs 7b and 7c). The highest force influence with the model was 175%. When the distal implant support in this model was placed in a position corresponding to that of a non-tilted implant (Fig 7c), the distal cantilever increased substantially, and a threefold magnification of the implant forces was found.32 This result confirmed that tilting the implant and increasing the supporting prosthesis base may give the desired reduction in implant forces.

**DISCUSSION**

The clinical results of this study indicate that implant tilting per se does not induce any biologic disadvantage. On the contrary, it seems to be both clinically and biologically advantageous, and a tilted implant as a member of a prosthesis configuration can be well justified from a biomechanical point of view.

The only implant losses were in the maxilla, and only 1 tilted implant (n = 40) was lost after loading, but 6 non-tilted (n = 98) implants were lost. There were also more non-tilted implants classified as surviving because of greater bone resorption (14 non-tilted versus 2 tilted). The reason for the improved situations for the tilted implants may be that they were longer and had a larger contact area with cortical bone, particularly in the posterior region. Both these improvements were made possible by the tilting per se.

The strain gauge measurements in one patient showed no significant differences in either axial force or bending moment between tilted and non-tilted implants within the same prosthesis. This means that implant loading was not influenced by tilting. The axial force (ie, following the long axis of the implant) of the tilted implant, however, may cause a lateral force component relative to the bone. If this were the case, the same lateral force must be counteracted by the prosthesis by reason of force equilibrium and would consequently have been registered as bending moments at the abutment level. Since the bending moments were small overall, this potential lateral force is of a relatively low magnitude. A possible explanation is that the rigidity of the prosthesis may counteract such bending, provided the implant is part of a restoration structure.

The theoretical calculations suggest that the increased supporting prosthetic base results in a threefold decrease of the forces acting on the implants in the particular case studied. Thus, from a biomechanics point of view, the position of the coronal end of the implant, rather than whether the implant is tilted or not, is most important.

In vivo measurements were carried out on only one prosthesis in one patient. However, general conclusions may be drawn. Repeating the measurement in other patients would have introduced variations in geometry and structure flexibility. The geometric variations were considered in the theoretical model, confirming the conclusions on force distribution from the measurement and being in accordance with other similar in vivo measurements.36 The bending moments were not considered in the model, but the measurements indicate that with the order of magnitude in the flexibility of prosthesis and bone, there is no measurable influence from the tilting. To alter this situation, a change in order of magnitude of the prosthesis and bone flexibility must be at hand, a situation that is unlikely in practice.
Figs 7a to 7c  Influence coefficients. The horizontal axis indicates position of load application, and the vertical axis indicates the proportional recorded force (as a percentage) in each of the 3 supporting implants.

Fig 7a  The measured case (note the different scale of this graph compared to Figs 7b and 7c).

Fig 7b  Theoretical model with tilted distal implant. This corresponds to the measured case.
The clinical implication of this study is that more patients can be successfully treated with dental implants without more complex techniques, such as nerve transposition in the mandible or grafting of the maxilla. Treatment of some of the patients in this study would not have been possible with conventional placement without grafting or other more demanding procedures. Tilting per se is not considered to be more complicated than conventional implant placement, as experienced by the authors.

CONCLUSIONS

The method of tilting implants described for treatment of edentulous arches represents an alternative or complementary technique to others mentioned in the literature. It leads to an improved position of the support and allows for placement of longer implants and/or improved anchorage in dense bone. Biomechanical measurements show that the tilting does not have a negative effect on the load distribution when it is a part of prosthesis support.

The advantages are further extension of the prosthesis in a posterior direction, possible use of longer posterior implants, and improved bone anchorage. The technique is relatively easy to perform in any outpatient setting by a surgeon who is not familiar with transpositioning of the mandibular nerve or bone grafting of the maxillary sinus. Furthermore, it eliminates the need for such advanced techniques for some patients.

REFERENCES